Characterization of EUV Mirror Capping Layers with Angle-resolved XPS

College of Nanoscale Science & Engineering
University at Albany State University of New York

Tyler R. Mowll[a], Eng Wen Ong[a], Arun J. Kadaksham[b], Frank Goodwin[b], David Balachandran[b], Michael A. Collings[a], Alex Hartwell[a], Sarah Mead[a†], Carl A. Ventrice, Jr.[a]

[a]*College of Nanoscale Science and Engineering, University at Albany-SUNY, 257 Fuller Rd., Albany, NY 12203*
[b]*SEMATECH North, 257 Fuller Rd., Albany, NY 12203*
[†]*Present Address: Dept. of Mechanical & Aeronautical Engineering, Clarkson University, Potsdam, NY 13699*

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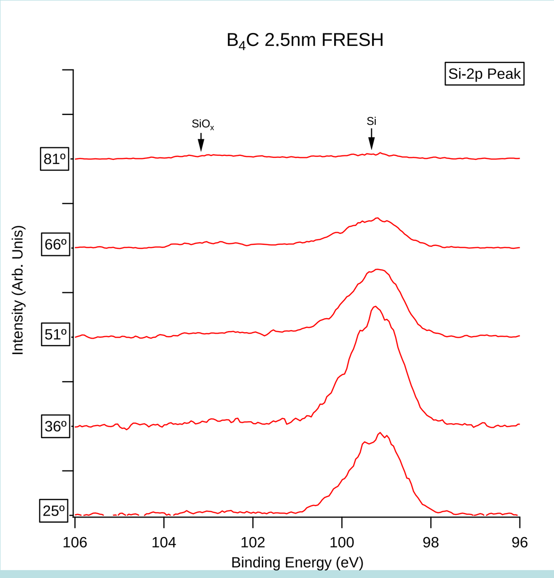
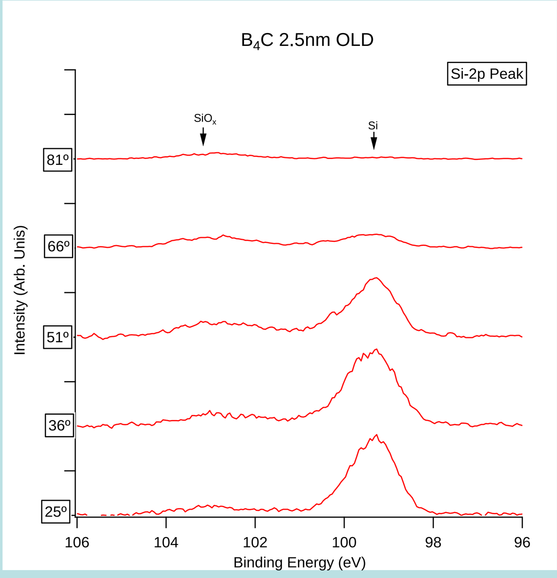
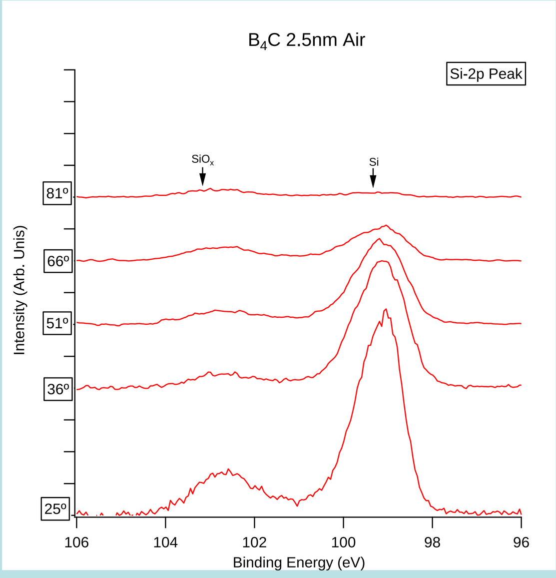
Abstract

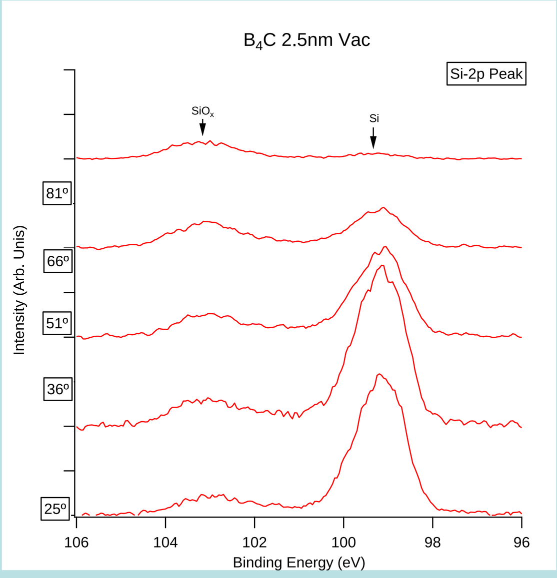
Since the photon energy of EUV light exceeds the band gap of all materials used in refractive optics, it is necessary to use reflective optics when performing EUV lithography. These mirrors consist of Si/Mo stacks and have a protective capping layer. Upon exposure to air, oxidation of the capping layer and diffusion of oxygen through the capping layer to the outermost Si layer may occur. In addition, Si may diffuse through the capping layer to the surface, resulting in a surface SiOx layer. The presence of oxygen will result in absorption of EUV radiation and distortion of the image. In this study, angle-resolved XPS measurements were performed on mirrors with capping layers of either Ru or B_4C. This technique allows extreme surface sensitive analysis of the elemental composition of the mirror. Our results indicate that for Ru capping layers that have a thickness of 2.5 nm, Si diffusion to the surface occurs at room temperature. Annealing the mirror was found to enhance the diffusion rate. For mirrors with a B4C capping layer, very little Si diffusion was observed at room temperature. After annealing the B4C mirrors to 250^{0}C, only a slight amount of Si diffusion was observed.

Angle Resolved B_4C Si Spectra



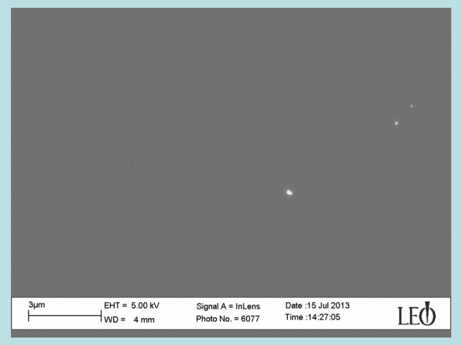


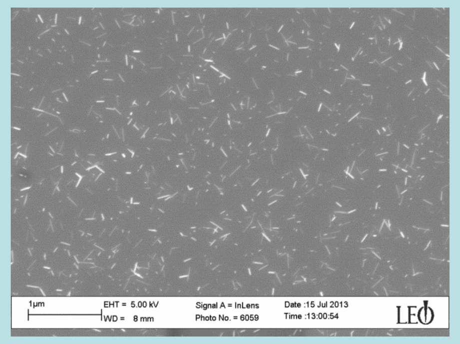


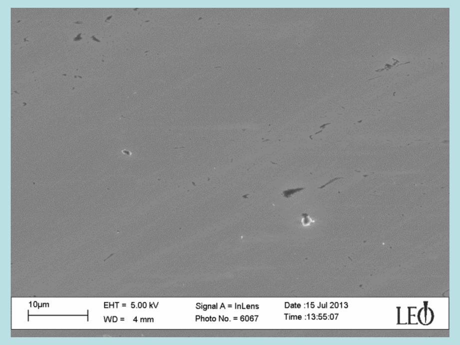


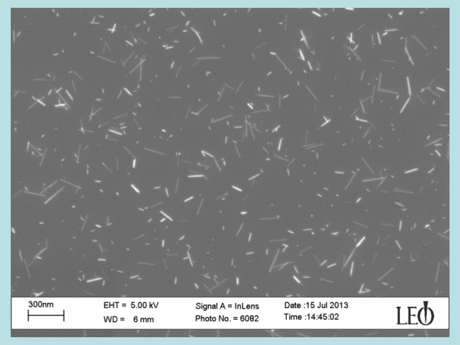
B_4C is a robust capping layer. Neither heat nor time result in significant Si diffusion

2.5nm Ru Capping Layer UV/DIW Cleaning Experiment

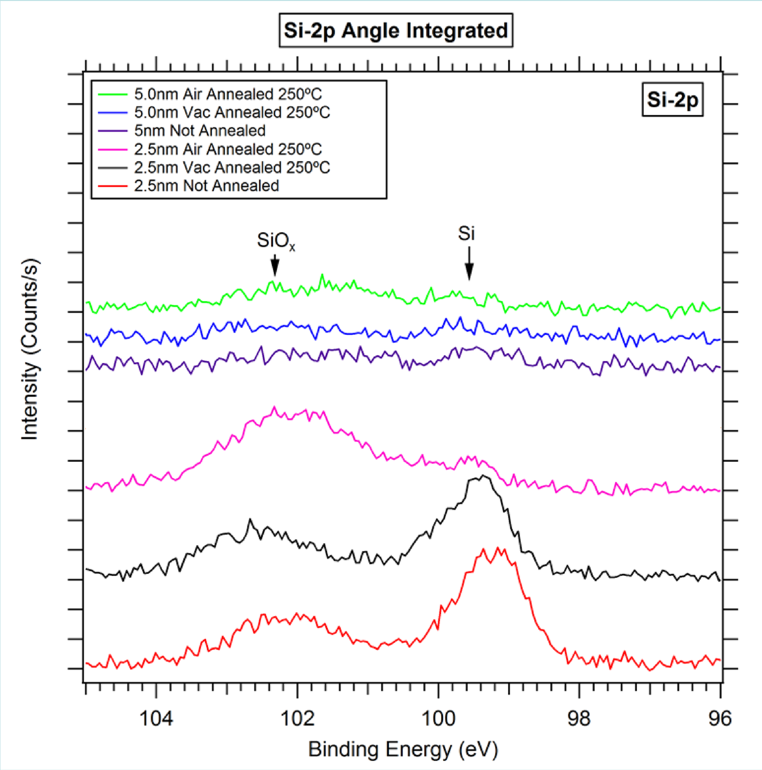

Cleaned 5x

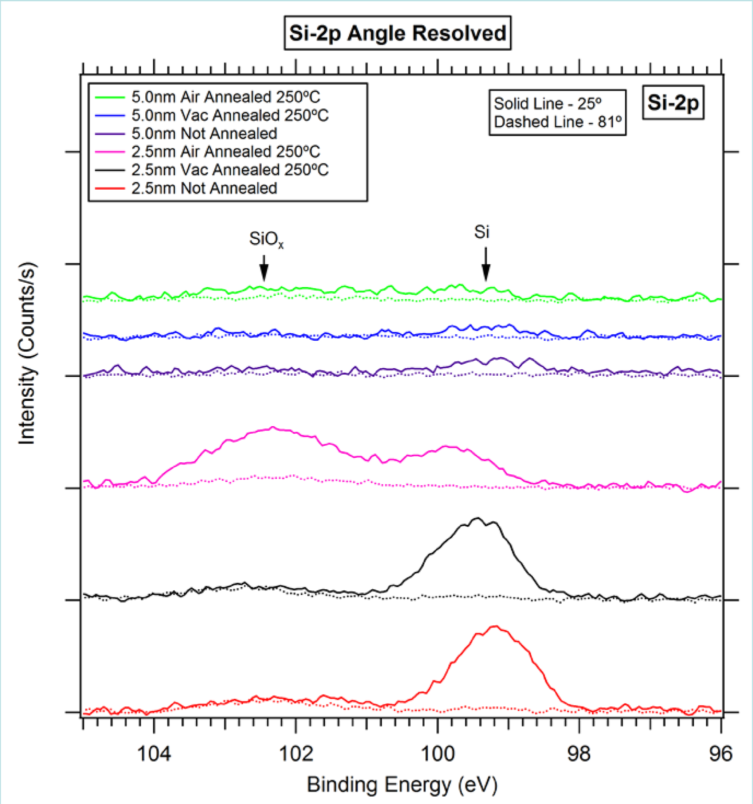

5X Cleaned then Annealed


Cleaned 50X


Cleaned 50X then Annealed

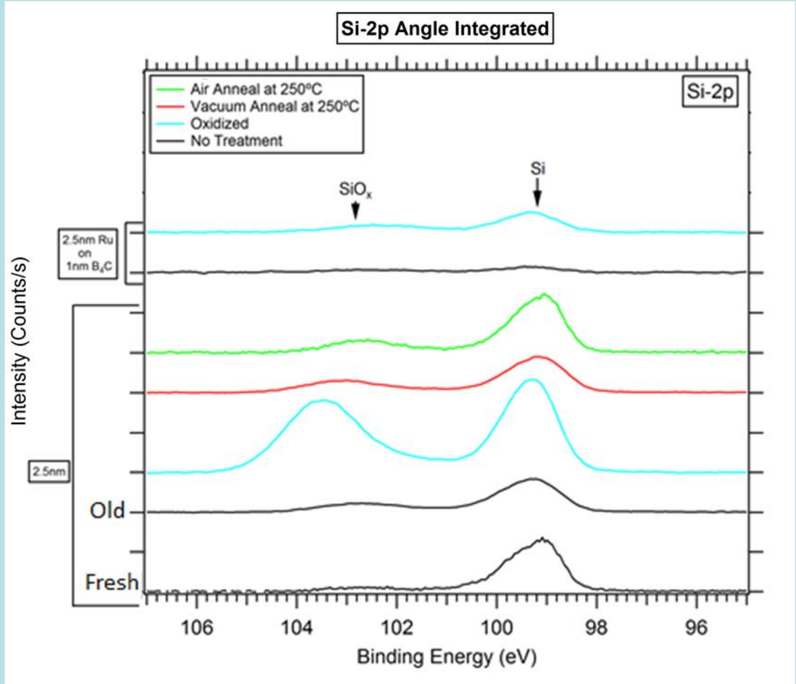
Ru Si Spectra

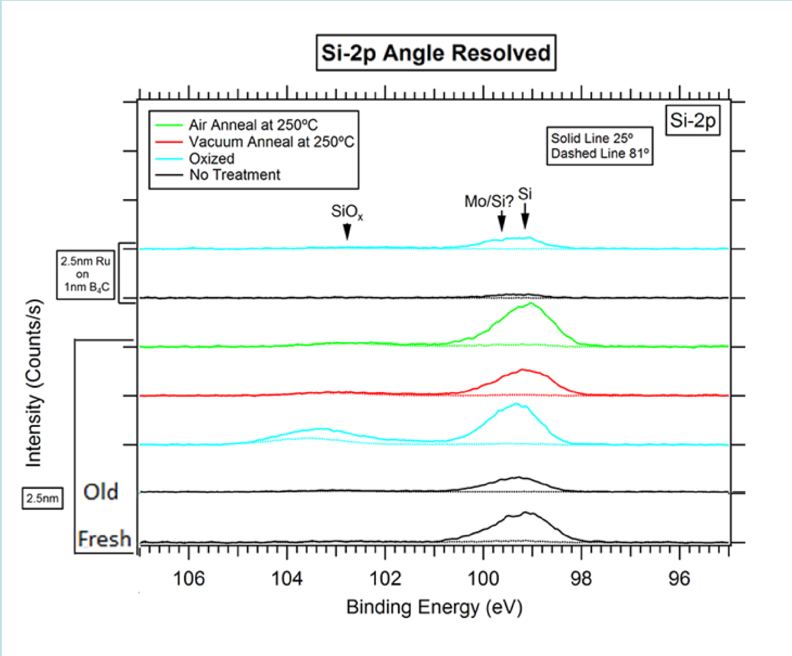




- Si does not diffuse to the surface with a 5nm Ru capping layer except after anneal
- SiO_x dominates in air anneal
- There might be some silicide formation at the interface upon annealing
  - Peaks are slightly asymmetric
  - Slight shift of peak

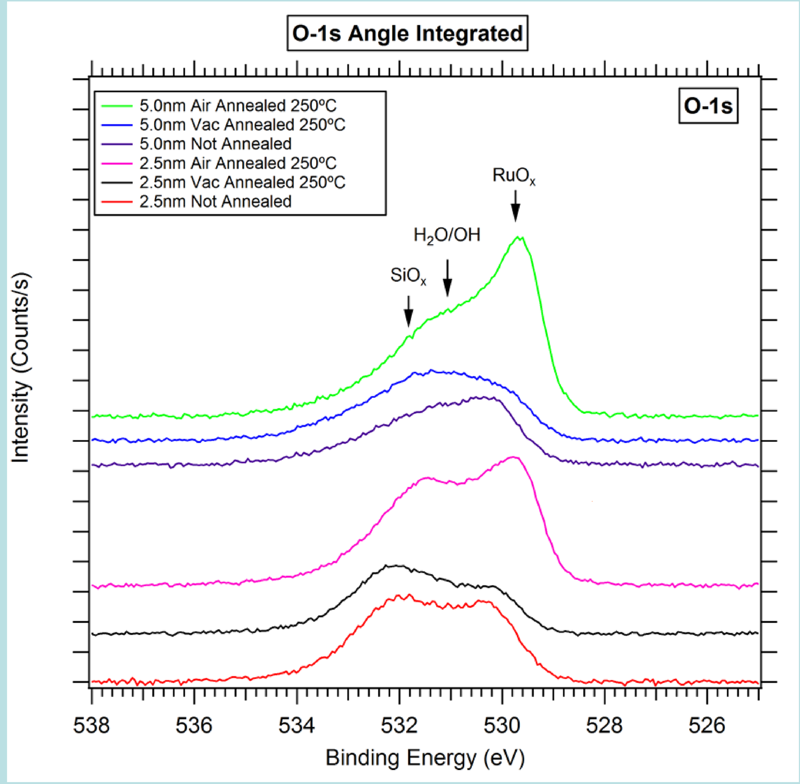
B_4C and B_4C /Ru Si Spectra

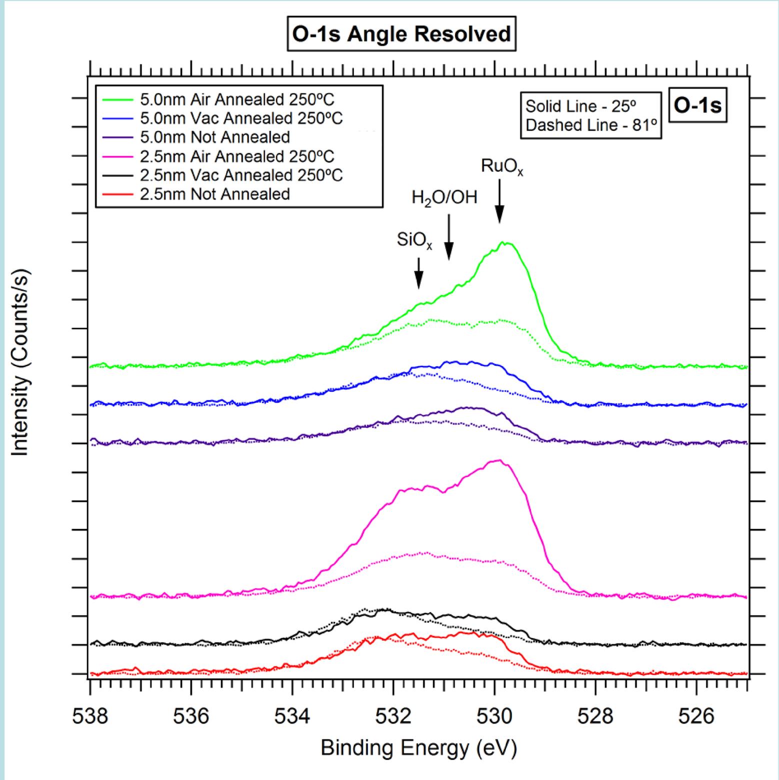




- B_4C remains robust against Si diffusion and oxidation under many different conditions
- The 1 nm of B_4C on top of 2.5nm Ru offers some protection, though it may be due to the total thickness of the capping layer

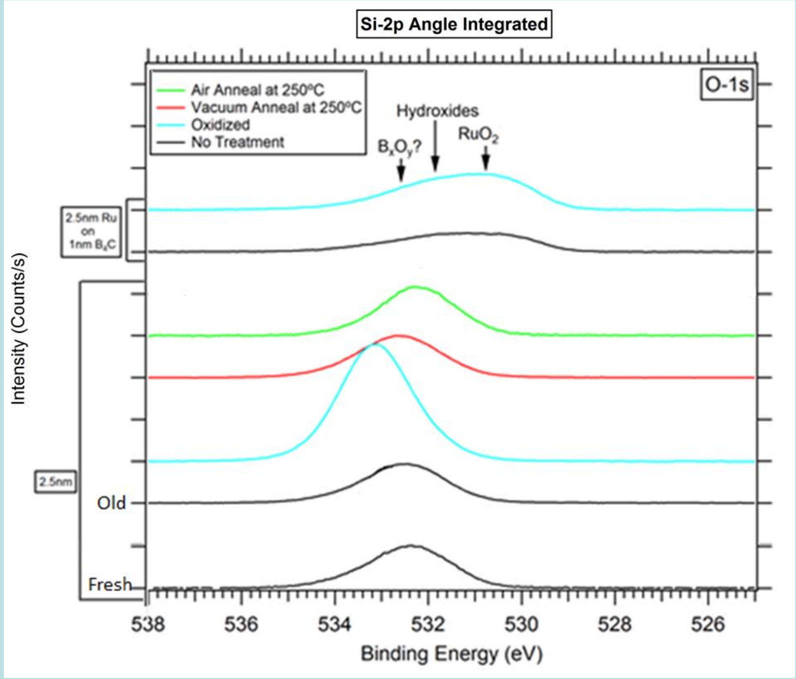
Ru Si Spectra

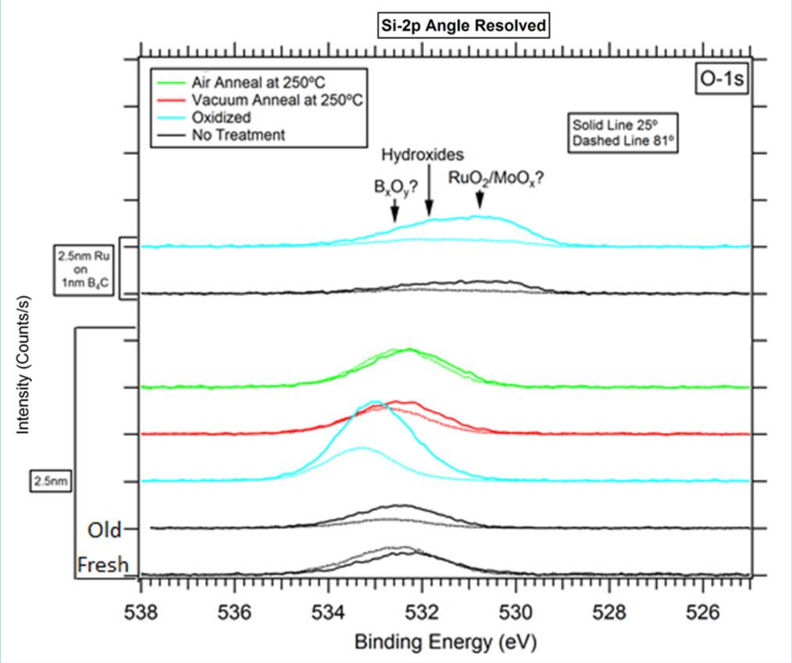




- Air anneal leads to greater oxidation
- A thin water/hydroxide layer is present on top of the capping layer
  - Surface sensitive scan shows a drop in RuO_x peak intensity
  - SiO_x **is** present in the 5nm Ru samples (see Si-2p slide) SiO_x peak becomes more prominent after H2 dosing the air annealed sample
- SiO_x peak becomes more prominent after Vac annealing the 5nm sample

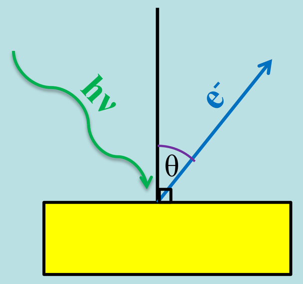
B_4C and B_4C /Ru O Spectra





- B_4C is not easily oxidized
- The 1 nm of B_4C on top of 2.5nm Ru offers some protection to the Ru layer, though it may be due to the total thickness of the capping layer

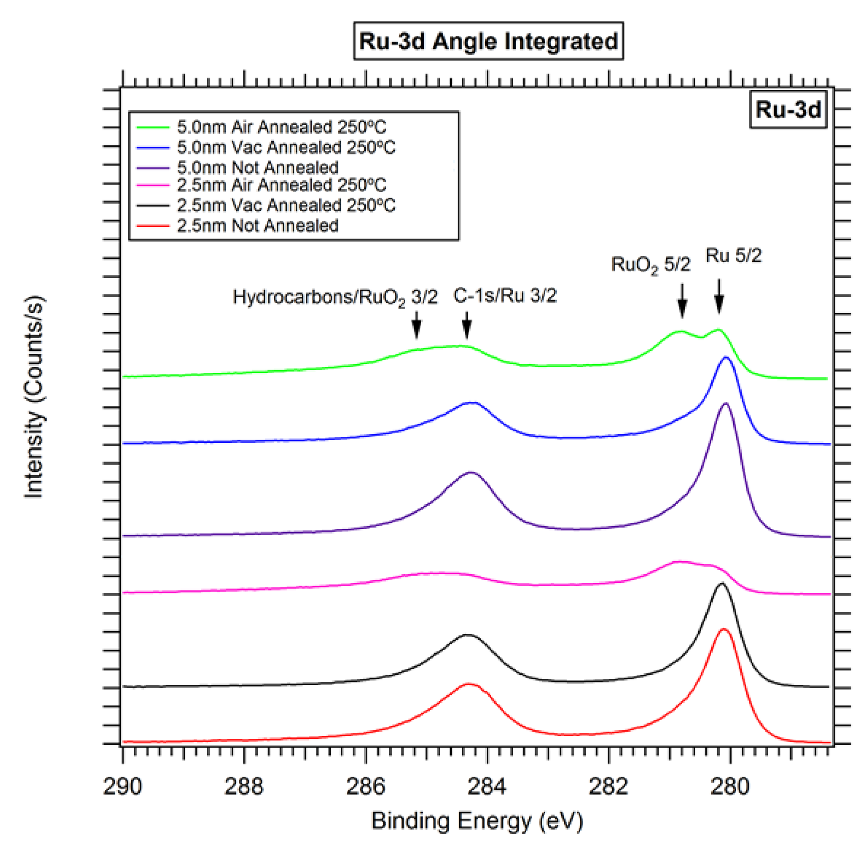
Understanding XPS

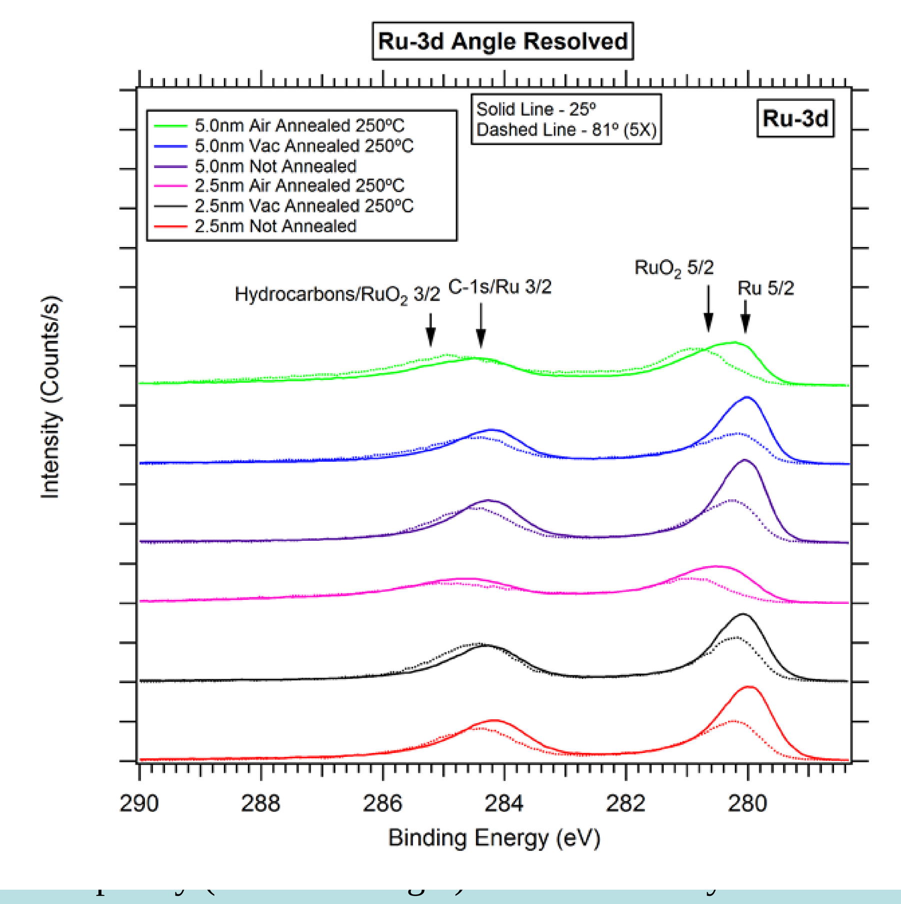


High energy monochromatic photons strike the sample and eject electrons. The binding energy of the electrons is equal to the energy of the incident photon energy minus the kinetic energy of the photoelectron and the work function of the sample. The spectra of binding energies are then compared to literature values for elemental and chemical state analysis. By changing the detection angle, it is possible to change the surface sensitivity. The angle is measured off of the surface normal (the greater the angle, the more surface sensitive the measurement is).

Conclusion

- Si diffuses through 2.5 nm thick ruthenium capping layers at room temperature
- Thicker Ru can be used, but this reduces reflectivity
- No Si diffusion is found for 2.5 nm B_4C capping layers





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lattice spacing close to that of half the wavelength of 13.5 nm light. Additionally, the components of the two layers must not significantly diffuse into one another. For our experiment, forty alternating layers of silicon and molybdenum of about 3.5 nm thickness were used. In addition, a 2.5 nm capping layer of ruthenium was deposited to prevent the oxidation of the top layer of silicon, and to act as an etch stop for the development of a reflective mask.